AN INITIAL STUDY OF A LOUVRE

TYPE DUST SEPARATOR

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TYPE DUST SEPARATOR

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SYMBOLS

a - Angle between louvre face and duct axis

B - Angle between louvre face and transverse blade axis

C - Dust concentration - grams dust per pound air

d - Blade spacing measured along louvre face

DP - Pressure difference - inches of water

DP^a - Pressure difference - inches of alcohol

E - Separation efficiency

f - An unknown function

F_c - Centrifugal force

G - Dust flow within narrow band

G_o - Dust flow into separator

G_x - Dust flow escaping through separator

G_e - Dust flow into narrow band

g - Acceleration due to gravity

L - Total length of louvre measured parallel to duct axis

L - Dimension of length

M - Particle mass

P - Static pressure - inches of water

r - Radius of curvature of particle path

S - Blade shape factor

T - Temperature - degrees F.

T - Dimension of time

t - Blade spacing measured on louvre face

V - Partial velocity

V_o - Air velocity

V_i - Partial terminal velocity

W - Louvre characteristic

x - Direction parallel to duct axis

y - Direction perpendicular to duct axis

ϕ - Dimensionless group of variables

θ - Geometrical characteristic of separator

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I. INTRODUCTION

For many years there has existed the problem of the removal of solid particles from a stream of gases. Previously, concern was mainly with large particles such as saw dust, and husks and shells from various food preparation operations. This type of separation is handled very well with cyclone type separators.

In recent years, however, more difficult requirements for particle separators have brought about a need for more efficient and compact collection equipment. Smoke abatement laws have brought about a need for the removal of fly ash from the flue gases of furnaces. The development of the coal burning gas turbine requires that the ash be removed from the high temperature gas stream (1300° F. approx.) before it is admitted to the turbine. These problems and others have been met with improvements in mechanical, and filter type separators, and the development of electrical separators.

This report presents the findings of an initial study of the collection possibilities of a louvre type mechanical separator. A mathematical analysis is presented and performance data for a model separator are reported.

II. DISCUSSION OF THE SEPARATOR

A louvre separator consists of a series of blades or vanes, called louvres, placed across the air stream in such a way as to cause the air velocity to make a sudden obtuse angle with its original direction and sense. As the air must turn with a very short radius, the centrifugal force tends to make the particle move in a straight line while the force of the air on the particle tends to make the particle follow the air stream. This causes the particle to move along a path of considerably less curvature than that of the air and thus strike a louvre. It then rebounds back into the dust laden air where the process is repeated until the dust reaches the end of the row of louvres or passes through the separator. See Figure 1. The separator, then, acts as a dust concentrator, collecting the separated dust at the end of the row of louvres where it may be removed by bleeding off a portion of the air at that point. This air will be referred to, in this report, as the blow down air.

The shape of the blades very likely affects the problem as does the angle in which they are placed in the separator. These factors determine the angle at which the particle strikes the surface of the louvre. If this angle is very small the particle is allowed to maintain its velocity towards the blow down intake. As this angle is increased the particle is retarded and is more likely to follow the curvature of the air and thus pass through the separator. This is due to the fact that the centrifugal force is proportional to the velocity of the particle squared, as seen in the well known equation:

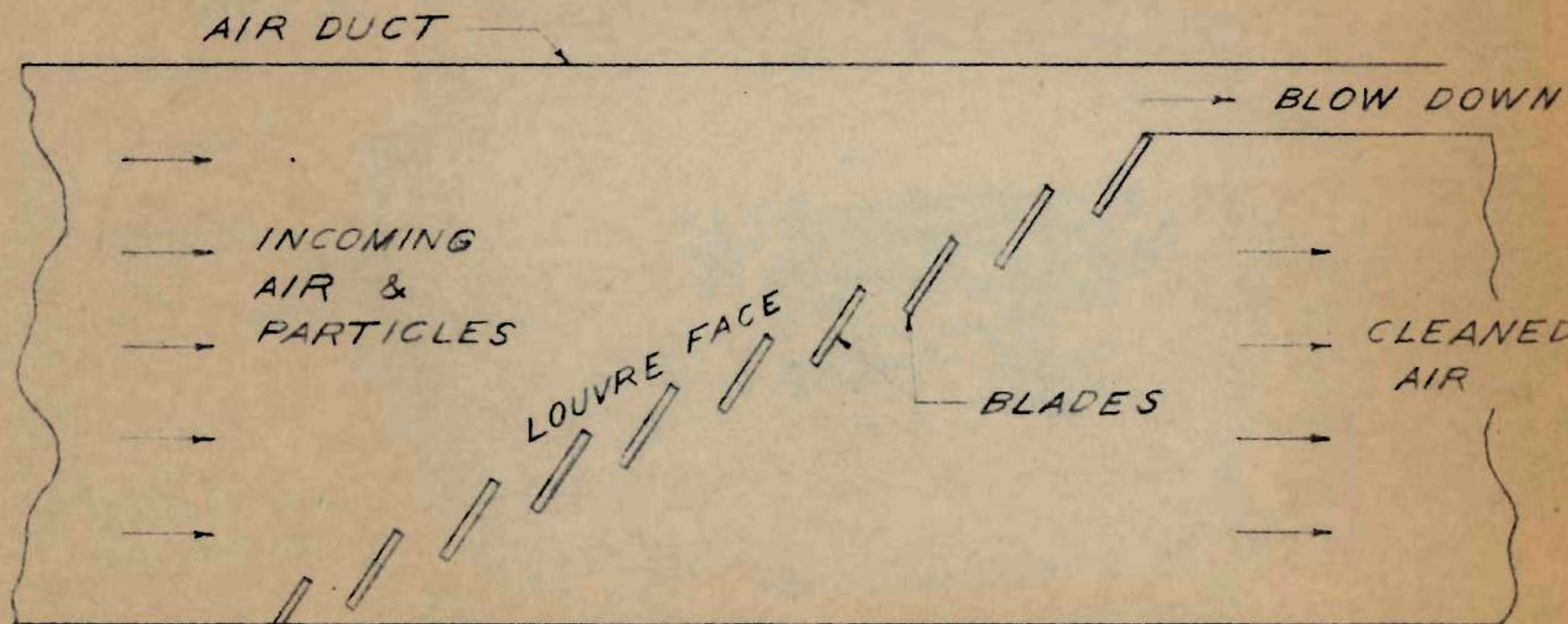

FIGURE 1
LOUVRE SEPARATOR

$$F_c = M\frac{V^2}{r}$$

Where F_c = centrifugal force

V = velocity of the particle

M = mass of the particle

r = radius of curvature of the particle path

The blade shape and angle also affect the pressure drop across the louvre which is of extreme importance in many separation applications.

The angle that the louvre face makes with the velocity of the air stream is another important geometrical factor. As the particle continually rebounds from the louvres, it must depend upon the component of air velocity parallel to the louvre face to carry it toward the blow down intake. If this component is high, the particle will travel a greater distance toward the blow down intake with each rebound than it would with a lower component. In traveling this greater distance the particle would strike the louvre face fewer times and thus decrease its chances of being passed through the separator. This velocity component of the air in a direction parallel to the louvre face depends directly upon the absolute air velocity and the cosine of the angle between the louvre face and the velocity of the air stream. Thus as this angle is decreased the parallel component of velocity is increased and separation is improved.

The characteristics of the particles will also affect separation. As can be seen by the equation above the centrifugal force on the particle is directly proportional to the mass of the particle which in turn depends upon its size and density. However, as the particle size increases, the force of the air on the particle due to relative motion between the air and the particle also increases. This force is also influenced by the shape of the particle. The three factors, density, size and shape, combine to determine the behavior of a particle moving in a given air stream. Therefore, it would be desirable to combine them into a single parameter which would be the only thing required to determine the behavior of a particle. This parameter has been found to be the terminal, or settling velocity of the particle.[1] This terminal velocity is the maximum rate at which the particle will fall through air at standard conditions and acted on by a standard gravitational field.

The amount of blow down air may also affect the problem. It is of interest also because in most applications this air must be cleaned by some secondary separator and then returned to the main air stream. Therefore, it would be well to keep this air at a minimum. However, separation may be improved by increasing this amount of air for a given blow down dust area. This would increase the parallel component of the air velocity near the blow down intake. Thus the separation would be improved at this point by the reasons shown above.

From the above discussion it can be seen that a louvre separator is most adaptable to the separation of particles conveyed through a duct by a gas having a velocity of the order of 150 feet per second.

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[1]Engineered Efficiency in Dust Collection and Recovery, Buell Engineering Company, 70 Pine Street, New York 5, N. Y.

III. ANALYTICAL ANALYSIS

Although not enough is known about the mechanics of separation to permit a complete mathematical analysis of the problem it is possible to make a few basic assumptions and develop an expression for the efficiency in terms of a few known quantities and a single parameter which is an unknown function of the remaining variables. This is done and an attempt is made to simplify this function by grouping the variables by dimensional analysis.

Efficiency

The separator used for this analysis is a plane louvre separator with two dimensional flow. The basic equation is first written for a separator containing no blow down. This equation may be modified for the type of blow down employed. The modification required for the type of blow down shown in Figure 1 is made.

Let it be assumed that the dust concentration of the air entering the separator is constant throughout the stream. Further an assumption is made that there is a band of dust with a vertical thickness "t" running parallel and adjacent to the louvre face. This band contains the dust which does not pass through the louvre face but is held close to it by the incoming air velocity. This dust flow "G" will move through the band toward the blow down intake. See Figure 2.

Next, let it be assumed that the dust escape "dG_x" through a point on the louvre face is directly proportional to G. If the number of particles flowing per second increases then the concentration of particles at that point increases in the same proportion. This increases

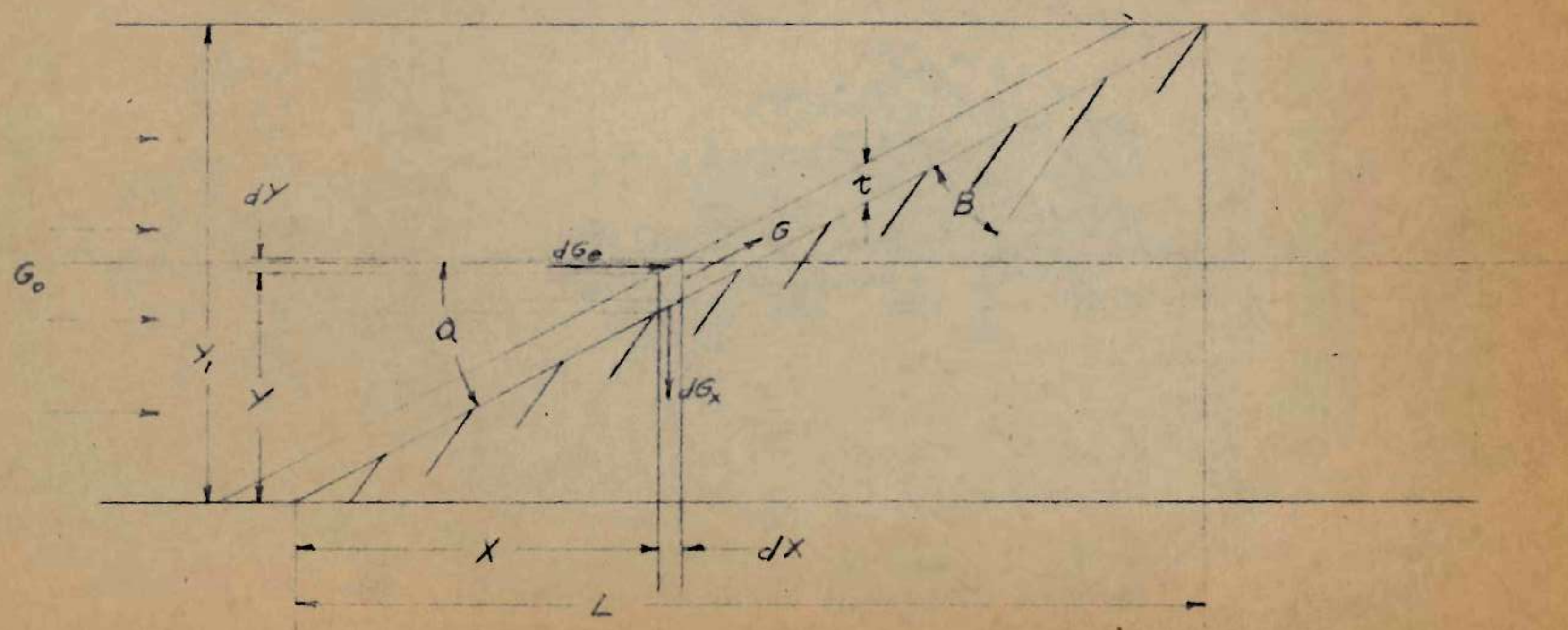

FIGURE 2
MATHEMATICAL NOTATION

the rate of escape of particles by the same proportion, because if there are two particles present the probability that one will escape is twice as great as it would be if only one were present. Written mathematically:

$$dG_x \propto G dx.$$

The total change in the flow of dust in the band is made up of the amount which enters the band "dGe" minus the amount which leaves "dG_x". The amount which enters the band is equal to the change in area "dy" of the duct times the flow per unit area of dust entering the separator $\frac{"G_o"}{y_1}$. Where G_o equals the total rate of dust flow into the separator. dG_e is negative due to the decrease in cross section of the separator.

The basic equation for the dust flow is now

$$(1) \quad dG = -\frac{G_o}{y_1} dy - WG dx.$$

Here "W" is a factor of proportionality which is a characteristic of the louvre and includes all remaining effects.

This equation will be solved for the plane louvre. For this case "W" is considered to be constant and

$$\frac{dy}{dx} = -\tan a.$$

Where a = the angle between the louvre face and the duct axis.

Now

$$dG = \frac{G_o}{y_1} \tan a \; dx - WGdx$$

$$\frac{dG}{WG - \frac{G_o}{y_1} \tan a} = - dx$$

Integrating from $x = 0$ to $x = L$

$$(2) \quad \frac{WG_2 - \frac{G_o}{y_1} \tan a}{WG_1 - \frac{G_o}{y_1} \tan a} = e^{-WL}$$

Where $G = G_1$ at $x = 0$

$G = G_2$ at $x = L$

The efficiency "E" of the separator will be defined as the rate percentage of dust collected to the total rate into the separator.

For the simple case, shown by Figure 2

$$(3) \quad E = \frac{G_2}{G_o}$$

From (2)

$$G_2 = \frac{WG_1 - \frac{G_o}{y_1} \tan a + \frac{G_o}{y_1} \tan a \; e^{WL}}{We^{WL}}$$

But

$$G_1 = \frac{G_o}{y_1} t$$

Combining

$$E = \frac{W\frac{t}{y_1} - \frac{1}{y_1}\tan a + \frac{1}{y_1}\tan a\, e^{WL}}{We^{WL}}$$

But

$$\tan a = \frac{y_1}{L}$$

Therefore

$$E = \frac{1}{We^{WL}}\left(W\frac{t}{y_1} - \frac{1}{L} + \frac{e^{WL}}{L}\right)$$

Simplifying

$$(4)\quad E = \frac{1}{e^{WL}}\left(\frac{t}{y_1} + \frac{e^{WL}-1}{WL}\right)$$

This equation holds for the apparatus used in this report. See Figure 9. However if the blow down is arranged as shown by Figure 1 then (3) becomes

$$E = \frac{G_2 + \frac{G_0}{y_1}y_2}{G_0}$$

Where y_2 = the blow down duct width

Here

$$\tan a = \frac{y_1 - y_2}{L}$$

(4) becomes

$$(4')\quad E' = \frac{1}{e^{WL}}\quad \frac{t}{y_1} + \theta\quad \frac{e^{WL}-1}{WL}\quad + \frac{y_2}{y_1}e^{WL}$$

Where θ equals $\frac{y_1 - y_2}{y_1}$

Dimensional Analysis

The factor "W" in the expression for efficiency of the separator is a characteristic of the separator and thus it is assumed that its value depends upon the following variables.

Variable	Symbol	Dimensions
Blade angle	B	0
Louvre face angle	a	0
Blade spacing	d	L
Air velocity	v_o	L/T
Particle terminal velocity	v_t	L/T
Acceleration due to gravity	g	L/T^2
Blade shape factor	S	0

Only two dimensions are involved: Length (L) and Time (T).

The first three determine the geometry of the separator along with the blade shape factor. Any other measurements could be used instead of these provided they are sufficient to completely describe the geometry of the separator. The air velocity is assumed to be a factor since any change in this affects the centrifugal force acting on the particle as it tries to follow the air stream around a blade. The terminal velocity is the factor describing the particle characteristic as discussed on page 5.

These variables will be arranged in dimensionless groups. Grouping the variables having dimensions gives

$$v_o^{\,a}\, v_t^{\,b} g^c d^d$$

or, written dimensionally

$$(L/T)^a (L/T)^b (L/T^2)^c (L)^d.$$

For the group to be dimensionless the sum of the exponents of each dimension must be equal to zero.

$$(L) \quad a + b + c + d = 0$$

$$(T) \quad -a - b - 2c = 0$$

Adding

$$-c + d = 0$$
$$c = d$$

Therefore

$$a + b + 2c = 0$$

Or

$$d = c = -\frac{a+b}{2}$$

The group now becomes

$$\frac{v_o^{a}\, v_t^{b}}{(g\, d)^{\frac{a+b}{2}}} = \phi$$

Where ϕ is defined by the above

W may now be expressed as

$$WL = f\,(\phi,\ a,\ B,\ S)$$

The L appears in order to make the left hand side dimensionless.

Since a is a function of L and y_1 it may be good to replace a by their ratio.

$$WL = f\left(\phi, \frac{y_1}{L}, B, S\right)$$

It is not known whether or not this analysis is valid. It is given here as starting point from which further study may be made.

IV. APPARATUS

Air was supplied to the apparatus by a seven stage centrifugal blower which received air from the room and delivered up to approximately .15 pounds of air per second against a head of 38 inches of water at the outlet. The blower was connected to one end of a 3 inch pipe containing several air meters. The duct containing the louvre separator was connected to the discharge end of this pipe. After passing through these meters the head available at the separator was about 10 inches of water at maximum flow. The air supplied was metered with a standard nozzle which was one of the meters contained in the pipe. The calibration of this meter is given in Appendix B by Curve I.

The duct carrying the air was of rectangular cross section 2 inches high by 3 inches wide. See Figure 6. Immediately after entering this duct the air passed through a butterfly valve which was used to vary the air flow. After this, it passed through a venturi with a throat of about half the cross sectional area of the duct. The particles were introduced into the air at this throat. This was done so that the high turbulence in the diffuser section beyond would mix the particles evenly throughout the air. Eight inches beyond the venturi section the air went into the separator. The cleaned air, after passing through the separator, continued along its original line through an orifice and was discharged through a flannel bag into the room. The flannel bag did not catch the particles but did slow up the air sufficiently to allow them to drop into a box below. The blow down air left the separator at right angles to the direction of the main stream of air. This air passed through a standard vacuum cleaner bag into the room. A manometer was connected across this pipe and calibrated to meter the blow down air. See Curve II, Appendix B. The vacuum cleaner bag trapped the separated particles.

The separator was the same size as the duct and was 8 inches in overall length. See Figure 7. The top and bottom were of plexiglas into which were set the louvres. The louvre face was set at an angle of 23 degrees and was 5 1/2 inches long, measured along the duct axis. The separator contained ten blades evenly spaced .57 inches apart measured on centers along the louvre face, and set at an angle of 30 degrees with the louvre face. The blades were of rectangular cross section 1/2 inch wide by 1/16 inch thick. The blow down intake had a maximum opening of 1 by 2 inches which could be varied by a gate type damper. This damper controlled the amount of blow down air. The actual cross section of the air stream entering the separator was 2.1 inches high by 2.25 inches wide.

The dust was fed to the air by a piston-cylinder arrangement. See Figure 8. Air from a separate compressor was brought through a pressure reducing valve and introduced into the chamber above the piston. The space below the piston was filled with particles. The air then passed into the lower space through helical groves cut into the piston. This air then picked up some dust and carried it out of the apparatus through a hole in the center of the piston and piston rod. The air carrying the dust then passed through a tube and into the venturi section. The rate of dust feed was fixed by lowering the piston at the proper rate by a small telechron motor. The reducing valve was set to keep the dust level about a quarter of an inch below the piston. The dust used consisted of crystals of aluminum oxide. These crystals were of fairly consistent size ranging from approximately 40 to 100 microns. See Figure 5.

The other equipment used were thermometers, a stop watch, manometers, and a balance accurate to 10 milligrams.

V. PROCEDURE

The experimental data were obtained with two objectives in mind. The first was to attempt to show that the variables listed on page 11 were or were not the ones which actually determined the performance of the separator. The second objective was to test the validity of the mathematical analysis if the assumed variables were found to apply. If, however, the assumed variables were shown not to apply, the second objective was to determine the variables which do.

To determine the effect of one variable on the efficiency four runs were made, each with a different value of the chosen variable. Each of these runs was made with every other condition as constant as possible. The variable was carried through as great a range as the equipment would allow. The four points were plotted with efficiency as ordinate and the variable as abcissa. The resulting curve indicated the effect of the variable on the efficiency.

It is clear that with a homogeneous distribution of dust throughout the air the efficiency will equal the per cent of blow down without any aid at all from the louvre. This efficiency was plotted against blow down and labeled, "blow down effect." See Figure 3. This curve was then subtracted from the curve which was obtained by varying the blow down and measuring the total efficiency. The resulting curve was the effect that the louvre alone showed as the blow down was varied. The curve of total efficiency obtained by experiment was extrapalated to blow downs of zero and 100 per cent by observing that at zero blow down the efficiency would be zero whereas at 100 per cent blow down the efficiency would be 100 per cent.

A number of runs were made with various other conditions changed but since only two points were available for each change of condition no curves were drawn. The results of these tests are shown in Table VII for comparison.

The apparatus was equipped so that the following data could be taken: the separation efficiency, the air velocity, pressure and temperature, the blow down quantity and per cent, the pressure drop through the louvre measured from intake duct to outlet duct, and the pressure drop over the louvre measured between two points close to the ends of the louvre face.

VI. DISCUSSION

In general the results of the experimental data indicate that the theory of the mechanics of separation is very incomplete. Although the effect of many of the assumed variables was not investigated, the results were sufficient to show that a more valid explanation of the principle of separation must be made before experimental data can be correlated other than empirically.

The most obvious fault occurred when the velocity of the air stream into the separator was varied. The points obtained from these data scattered around a constant efficiency which indicated that the efficiency was independent of the air velocity within the range of this study. See Figure 3. This fact indicates that the function ϕ in the dimensional analysis on page 11 is in error or that the exponent "a" is equal to zero. The reason that efficiency is independent of the velocity is probably that although the centrifugal force on the particle and also the component of air velocity parallel to the louvre face increases, the force of the air on the particle tending to sweep it through the louvre face also increases. These effects evidently cancel each other to produce no resulting effect.

The concentration of dust also has no appreciable effect upon the efficiency of separation. This upholds the assumption that as the concentration of dust into the separator is changed then the concentration of dust at all other points changes by the same proportion thus leaving the efficiency the same. It is possible, however, that if the concentration is increased to the point where the particles affect the air flow or begin interfering with themselves any further increase may affect the performance of the separator.

It was assumed that the blow down would have little or no effect upon the efficiency provided the quantity of blow down air was large enough to carry away the separated particles. This however was shown not to be true as the efficiency increased rapidly as the blow down was increased to about 20 per cent. It can be seen by the curve of the effect of the louvre alone that the louvres have their greatest effect at 21 per cent blow down. This fact indicates that separation is strongly affected by the velocity distribution upstream from the louvres and not by the velocity distribution of the air immediately around the blades.

From the miscellaneous runs taken, see Table VII, it is noticed that the efficiency is greatly increased by opening the downstream side of the separator to the atmosphere. See Figure 9. The reason for this is not apparent although this greatly increases the amount of air which passes through the lower part of the louvre face. Evidently under normal conditions the greatest part of the air passes through the portion of the louvre which is closest to the blow down intake. This same effect would very probably be observed if the downstream side of the separator were enlarged instead of opened. The type of enlargement necessary in the present model is shown by the dotted line in Figure 9.

It is also noticed by runs 14 and 15 (see Table VII) that removing blades in the lower portion of the separator does not affect the efficiency while removing those close to the blow down intake lowers the efficiency considerably. This supports the statement above that under the normal operating conditions the greatest portion of the air passes through the upper part of the louvre face. These runs also show that the efficiency is improved by spacing the blades more closely together.

The question was considered as to whether or not the pressure drop over the face affected separation. The pressure difference between two points the same distance upstream from the louvre face, one close to the lower end and the other close to the upper end, showed about the same variation as the air velocity and the blow down were varied. Thus it was indicated that this pressure difference across the face had no direct influence upon the efficiency. See Figure 4.

It is also seen by Figure 4 that the pressure drop through the separator is only dependent upon the quantity of air through the separator since all points taken at different total air volumes and different blow down rates fell on the same curve.

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APPENDIX A

EXPERIMENTAL RESULTS

TABLE I: Dust Separation Data from Louvre Separator
Face Angle 23° Blade Angle 30°
Barometric Pressure 28.9 Inches of Mercury

Run Number	Duration (minutes)	Dust Input Weights (gm.) Before	Dust Input Weights (gm.) After	Separated Dust Weights (gm.) Before	Separated Dust Weights (gm.) After
	Runs Taken with Varying Air Velocity				
1	4	72.40	40.75	79.07	96.33
2	4	77.34	44.97	58.30	75.43
3	5	75.92	55.57	66.37	77.34
4	4	79.80	40.91	75.28	97.25
	Runs Taken with Varying Dust Concentration				
5	4	81.23	41.51	59.51	87.69
6	4	84.43	48.01	63.86	88.43
7	4	77.52	50.80	87.09	105.76
8	4	80.00	56.54	81.67	97.68
	Runs Taken with Varying Blow Down				
9	4	75.79	40.64	54.48	71.70
10	4	78.40	46.48	52.59	73.03
11	4	78.36	40.38	70.09	98.41
12	3	81.77	58.72	62.99	81.10
13	3	81.25	59.59	61.29	78.94
	Run number 1 is also used in the above group.				
	Run Taken with Blades 2, 4, 6 and 8 Removed				
14	4	75.52	44.97	57.68	74.70
	Run Taken with Blades 3, 5, 7 and 9 Removed				
15	4	77.28	47.71	59.12	69.62
	Runs Taken with Exit Part of Separator Open				
16	4	77.57	40.67	51.47	76.76
17	4	76.39	33.31	62.88	95.39

TABLE II: Air Condition and Distribution Data for Table I
Face Angle 23° Blade Angle 30°
Barometric Pressure 28.9 Inches of Mercury

Run Number	Nozzle DP	Nozzle T	Separator T	Blow Down Pipe DP[a]
	Runs Taken with Varying Air Velocity			
1	5.3	94	88	0.95
2	4.4	94	88	0.78
3	3.1	95	88	0.55
4	2.5	96	88	0.45
	Runs Taken with Varying Dust Concentration			
5	6.6	100	94	---
6	6.6	100	95	---
7	6.6	100	94	---
8	6.6	100	94	---
	Runs Taken with Varying Blow Down			
9	6.2	95	89	0.87
10	6.5	95	89	1.79
11	6.6	95	89	3.50
12[1]	6.8	101	95	---
13[1]	6.9	101	96	---
	Runs Taken with Blades 2, 4, 6 and 8 Removed			
14	5.5	96	90	0.98
	Runs Taken with Blades 3, 5, 7 and 9 Removed			
15	5.3	98	93	0.95
	Runs Taken with Exit Part of Separator Open			
16	6.70	95	89	0.99
17	2.85	95	89	0.44

DP = Pressure difference - inches of water
DP[a] = Pressure difference - inches of alcohol
T = Temperature °F

[1]These points were taken from a previous curve for which the actual blow down was unknown.

TABLE III: Pressure Data from Louvre Separator
Face Angle 23° Blade Angle 30°
Barometric Pressure 28.9 Inches of Mercury

Run Number	Nozzle DP	Nozzle P	Nozzle T	Blow Down Pipe DP[a]
	Runs Taken with Varying Air Velocity			
18	6.3	15.9	91	0.86
19	4.9	21.8	91	0.66
20	3.6	26.8	92	0.48
21	2.9	29.4	92	0.38
	Runs Taken with Varying Blow Down			
22	6.1	29.4	92	0.21
23	6.45	29.4	92	1.80
24	6.5	29.4	92	3.50

Run Number	Separator DP	Separator P	Separator T	Face Drop DP
	Runs Taken with Varying Air Velocity			
18	5.45	4.3	86	1.75
19	4.35	3.3	86	1.50
20	3.25	2.5	86	1.15
21	2.70	2.0	86	1.00
	Runs Taken with Varying Blow Down			
22	5.75	4.8	87	1.20
23	5.00	3.6	87	1.90
24	4.60	3.2	88	2.20

TABLE IV: Air Distribution Results
Face Angle 23° Blade Angle 30°

Total Air

Run Number	Duration (minutes)	Nozzle DP	Flow (lbs./sec.)	Air Volume (ft.^{3}/lb.)	Velocity (ft./sec.)
1	4	5.3	0.127	14.3	55.4
2	4	4.4	0.115	14.3	50.2
3	5	3.1	0.096	14.3	41.9
4	4	2.5	0.086	14.4	37.5
5	4	6.6	0.142	14.4	62.2
6	4	6.6	0.142	14.4	62.2
7	4	6.6	0.142	14.4	62.2
8	4	6.6	0.142	14.4	62.2
9	4	6.2	0.138	14.3	60.1
10	4	6.5	0.141	14.3	61.5
11	4	6.6	0.142	14.3	61.9
12	3	6.8	0.144	14.4	62.8
13	3	6.9	0.145	14.4	63.2
14	4	5.5	0.129	14.3	56.3
15	4	5.3	0.127	14.4	55.4
16	4	6.7	0.143	14.3	62.4
17	4	2.8	0.092	14.3	40.1

Blow Down

Run Number	DP[a]	Flow	Per Cent
1	0.95	0.0146	11.5
2	0.78	0.0132	11.5
3	0.55	0.0111	11.5
4	0.45	0.0101	11.7
5	----	------	----
6	----	------	----
7	----	------	----
8	----	------	----
9	0.87	0.0140	10.1
10	1.79	0.0200	14.2
11	3.50	0.0281	19.8
12	----	------	----
13	----	------	----
14	0.98	0.0148	11.5
15	0.95	0.0147	11.6
16	0.99	0.0149	10.4
17	0.44	0.0100	10.9

TABLE V: Efficiency Results
Face Angle 23° Blade Angle 30°

Run Number	Dust Input (gm.)	Dust Separated (gm.)	Dust Flow (gm/sec)	Concentration C	Efficiency %
1	31.65	17.26	0.132	1.04	54.5
2	32.37	17.13	0.135	1.17	53.1
3	20.35	10.97	0.034	0.35	53.9
4	38.89	21.97	0.162	1.88	55.4
5	39.72	28.18	0.165	1.16	70.9
6	36.42	24.57	0.152	1.07	67.4
7	26.72	18.67	0.111	0.78	69.9
8	23.46	16.01	0.098	0.69	68.2
9	35.15	17.22	0.147	1.06	49.0
10	31.92	20.44	0.133	0.94	64.5
11	37.98	28.32	0.158	1.11	74.5
12	23.05	18.11	0.128	0.89	78.5
13	21.66	17.65	0.120	0.83	81.5
14	30.55	17.02	0.127	0.98	55.7
15	17.99	6.23	0.075	0.59	34.7
16	36.90	25.29	0.154	1.08	68.5
17	43.08	32.51	0.180	1.96	75.5

C = Concentration - $\frac{\text{grams of dust}}{\text{lb of air}}$

TABLE VI: Pressure Results

Run Number	Pressure Drop Across Separator (in. water)	Air Flow (lb/sec)	Velocity (ft/sec)	Blow Down %
18	5.45	0.139	60.6	10.0
19	4.35	0.122	53.2	10.0
20	3.25	0.103	44.9	10.1
21	2.70	0.093	40.6	10.0
22	5.75	0.137	59.8	4.9
23	5.00	0.140	61.1	14.3
24	4.60	0.141	61.5	19.9

Run Number	Pressure Drop Over Face (in. water)	Blow Down Flow (lb/sec)	Quantity Air Thru Separator (lb/sec)
18	1.75	.0139	0.125
19	1.50	.0122	0.110
20	1.15	.0104	0.093
21	1.00	.0093	0.084
22	1.20	.0068	0.130
23	1.90	.0200	0.120
24	2.20	.0280	0.113

TABLE VII: Miscellaneous Results
Face Angle 23° Blade Angle 30°

RUN	1	14	15	16	17
Blades Removed	0	2, 4, 6, 8	3, 5, 7, 9	0	0
Exit Part of Separator	Closed	Closed	Closed	Open	Open
Air Velocity (ft/sec)	55.4	56.3	55.4	62.4	40.1
Blow Down (%)	11.5	11.5	11.6	10.4	10.9
Efficiency (%)	54.5	55.7	34.7	68.5	75.5

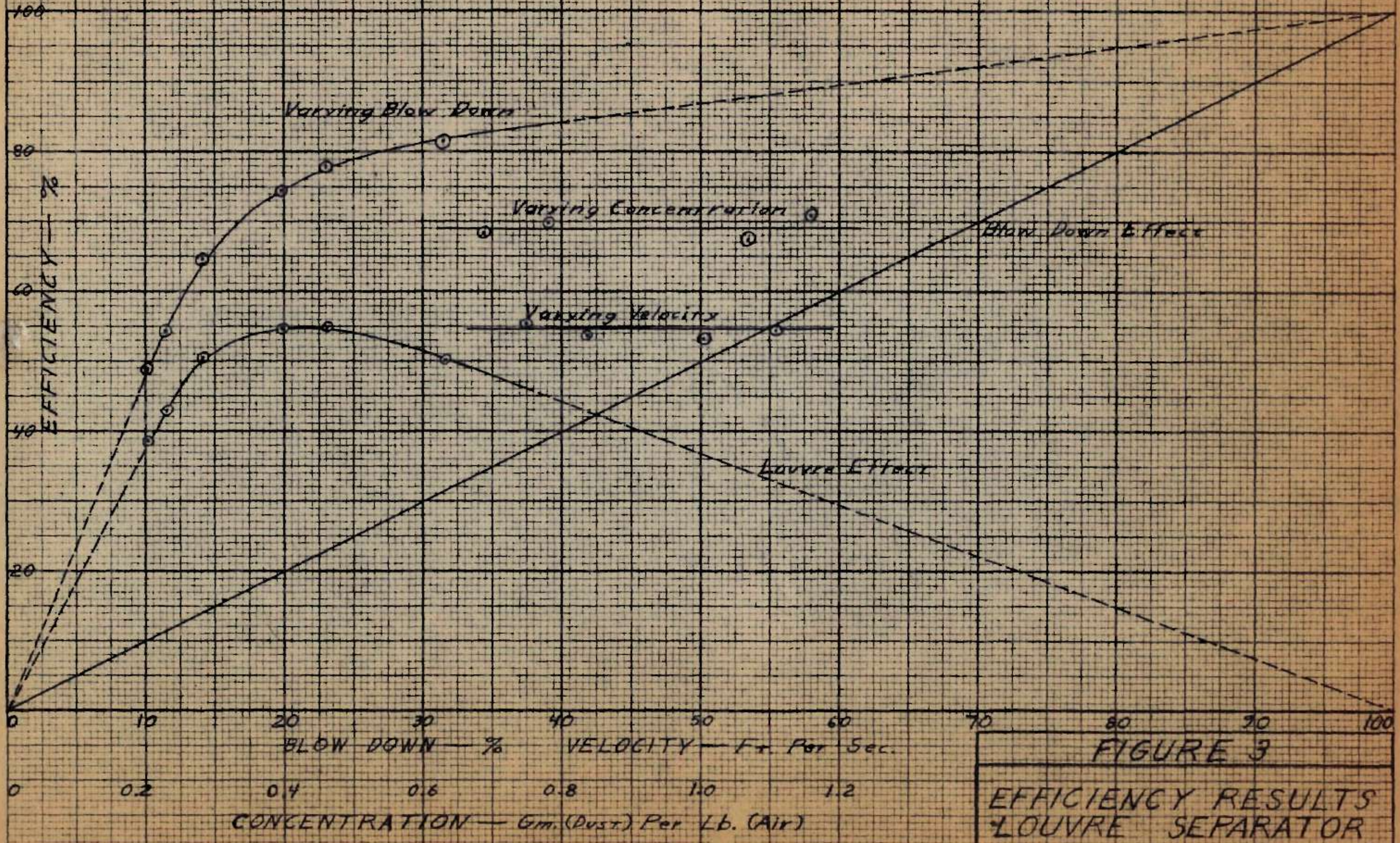


FIGURE 3

EFFICIENCY RESULTS
LOUVRE SEPARATOR
23° Face angle 30° Blade angle

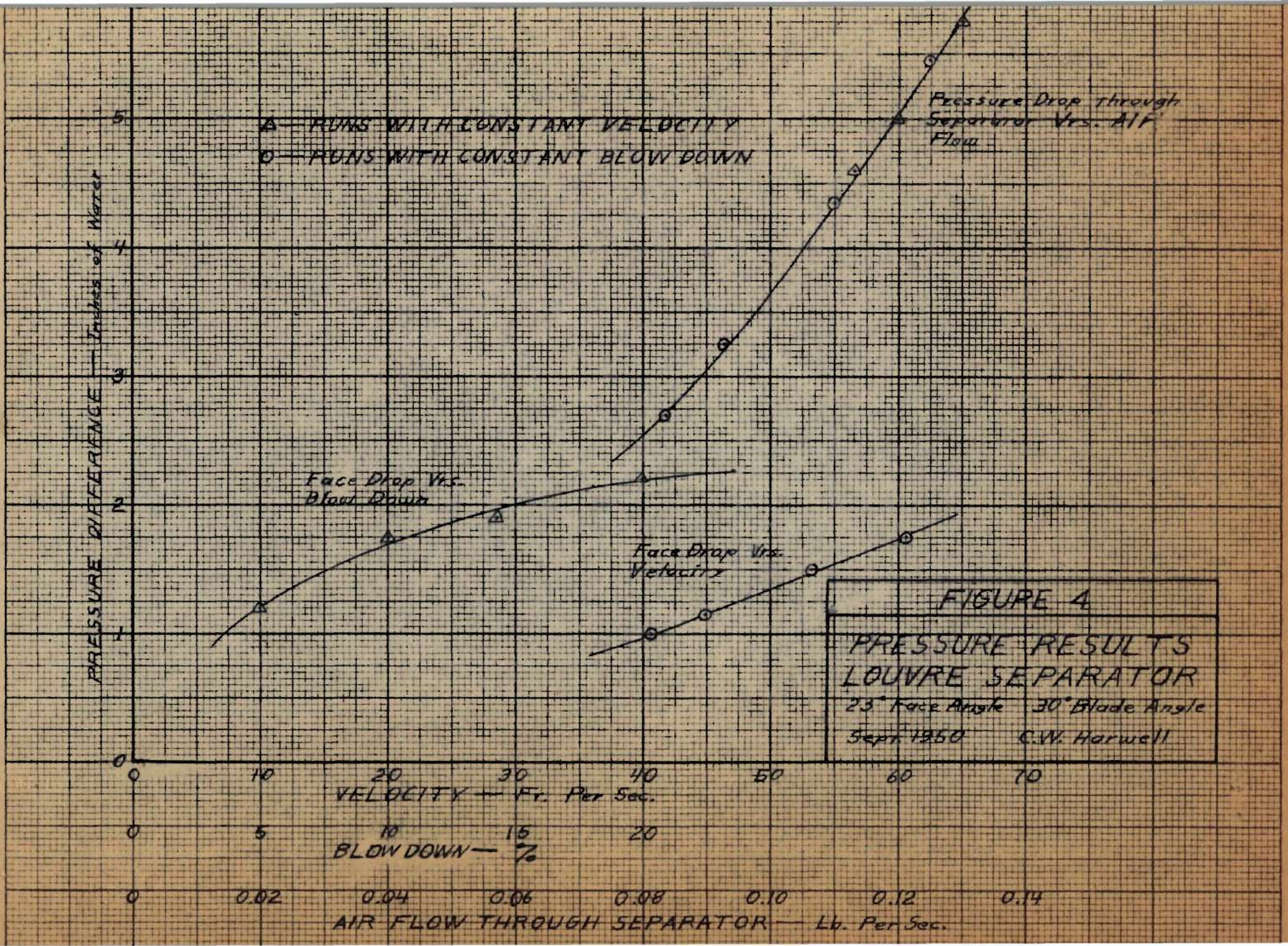


FIGURE 4

PRESSURE RESULTS
LOUVRE SEPARATOR
23° Face Angle 30° Blade Angle
Sept 1950 C.W. Harwell

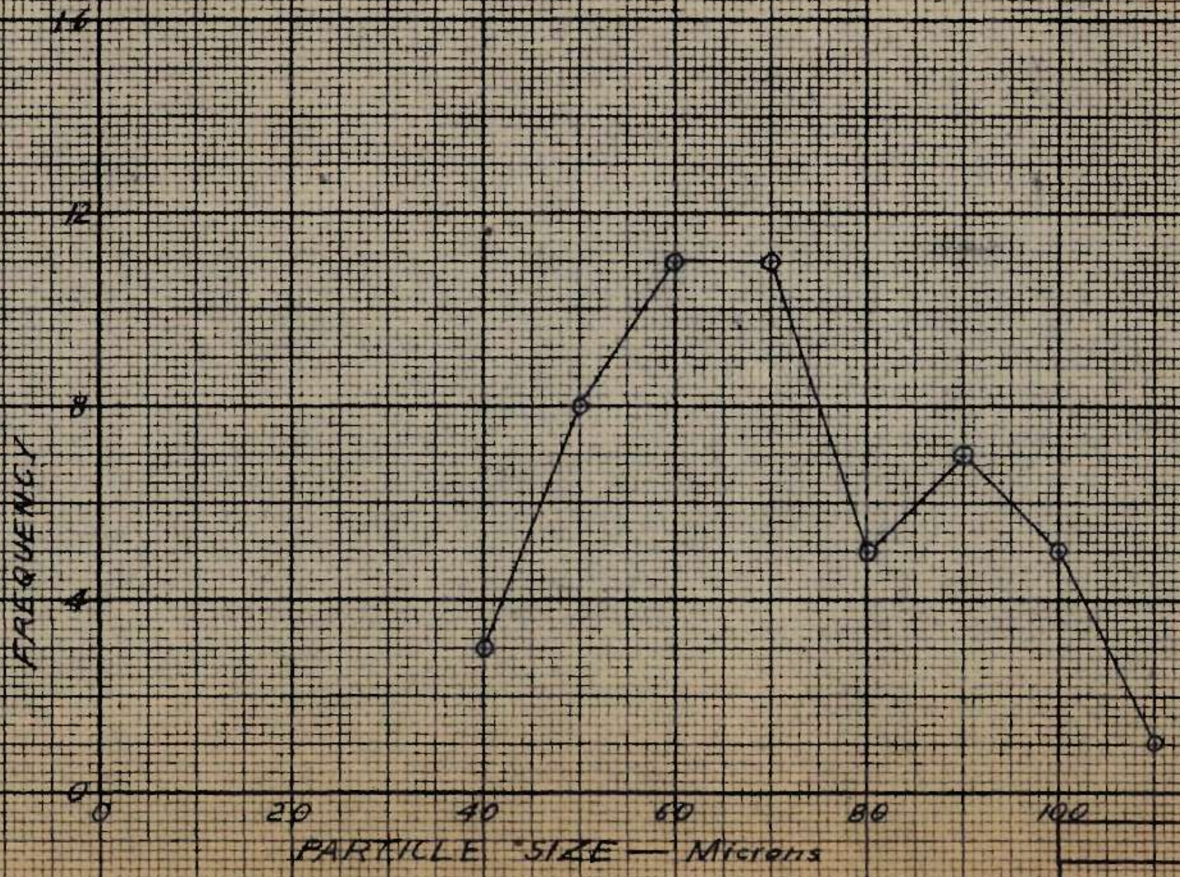


FIGURE 5

SIZE FREQUENCY DISTRIBUTION

51 Samples Aluminum Oxide Crystals

SAMPLE CALCULATIONS

Calculation of gas constant of room air

Barometric pressure - 29.08 inches of mercury
Room wet bulb temperature - 74° F
Room dry bulb temperature - 83.5° F

Carrier's equation

$$P_s = P_w - \frac{(P_b - P_w)(t_d - t_w)}{2800 - 1.3\ t_w}$$

where P_s = water vapor partial pressure lbs./in.^{2}
P_w = vapor pressure corresponding to wet bulb temperature lbs./in.^{2}
P_b = barometric pressure lbs./in.^{2}
t_d = dry bulb temperature
t_w = wet bulb temperature

$$P_s = .4156 - \frac{(14.28 - .4156)(9.5)}{2800 - 1.3 \times 74} = .367 \text{ lbs./in.}^2$$

$$P_d = 14.28 - .367 = 13.91 \text{ lbs./in.}^2$$

where P_a = air partial pressure

The weights of air and water in one cubic foot of mixture are

$$W_a = 2.7\,\frac{P}{T} = 2.7\,\frac{13.91}{543} = .0692 \text{ lbs.}$$

$$W_w = 1.68\,\frac{P}{T} = 1.68\,\frac{.367}{543} = .00113 \text{ lbs.}$$

The total weight = .0692 + .00113 = .0703 lbs.

The gas constant "R" for the mixture is now

$$R = \frac{P}{WT} = \frac{14.28 \times 144}{.0703 \times 543} = 53.8$$

This value remains constant enough to be used for all runs.

(1) Run 1

(2) Duration - 4 minutes (data)

(3) Nozzle DP - 5.3 inches of water (data)

(4) Flow - .127 lbs. per sec. (Figure 10)

(5) Specific volume of the air (v)

$$v = \frac{RT}{P}$$

R = gas constant (53.8)
T = absolute temperature
P = absolute pressure

$$v = \frac{53.8 \times 554}{14.2 \times 144} = 14.3 \text{ ft}^3/\text{lb}$$

(6) Velocity (V_o)

$$V_o = \frac{\text{v x flow}}{\text{duct area}}$$

$$\text{duct area} = \frac{2.25 \times 2.1}{144} = .0328 \text{ ft}^2$$

$$V_o = \frac{14.3 \times .127}{.0328} = 55.4 \text{ ft/sec}$$

(7) Blow Down pipe DP = .95 inches of alcohol (data)

(8) Blow Down Flow - .0146 lbs. per sec. (Figure 10)

(9) Blow Down per cent = $\frac{\text{Blow Down Flow}}{\text{Total Flow}}$

$$\frac{.0146}{.125} = 11.5\%$$

(10) Dust Input = wt. before - wt. after

72.40 - 40.75 = 31.65 gm.

(11) Dust Collected = wt. after - wt. before

$$96.33 - 79.07 = 17.26 \text{ gm.}$$

(12) Dust Flow = $\dfrac{\text{Dust Input}}{\text{Time}}$

$$\frac{31.65}{4 \times 60} = .132 \text{ gm/sec}$$

(13) Dust Concentration = $\dfrac{\text{Dust Flow}}{\text{Air Flow}}$

$$\frac{.132}{.127} = 1.04 \frac{\text{gm. of Dust}}{\text{lb. of Air}}$$

(14) Efficiency = $\dfrac{\text{Dust Collected}}{\text{Dust Input}}$

$$\frac{17.26}{31.65} = 54.5\%$$

(15) Pressure drop across separator - 5.45 inches of water (data run 18)

(16) Pressure drop over face 1.75 inches of water (data run 18)

(17) Quantity of air through separator = Total Flow - Blow Down Flow

$$.139 - .0139 = .125 \text{ lbs. per sec. (Run 18)}$$

NOTE: Runs 12 and 13 were taken from a previous curve of efficiency vs. blow down where the scale of the blow down was in error. However, this scale was corrected by superimposing the previous curve on the one included in this report. The fit of the two curves was close enough to allow runs 12 and 13 to be used in the later curve using their corrected blow down values.

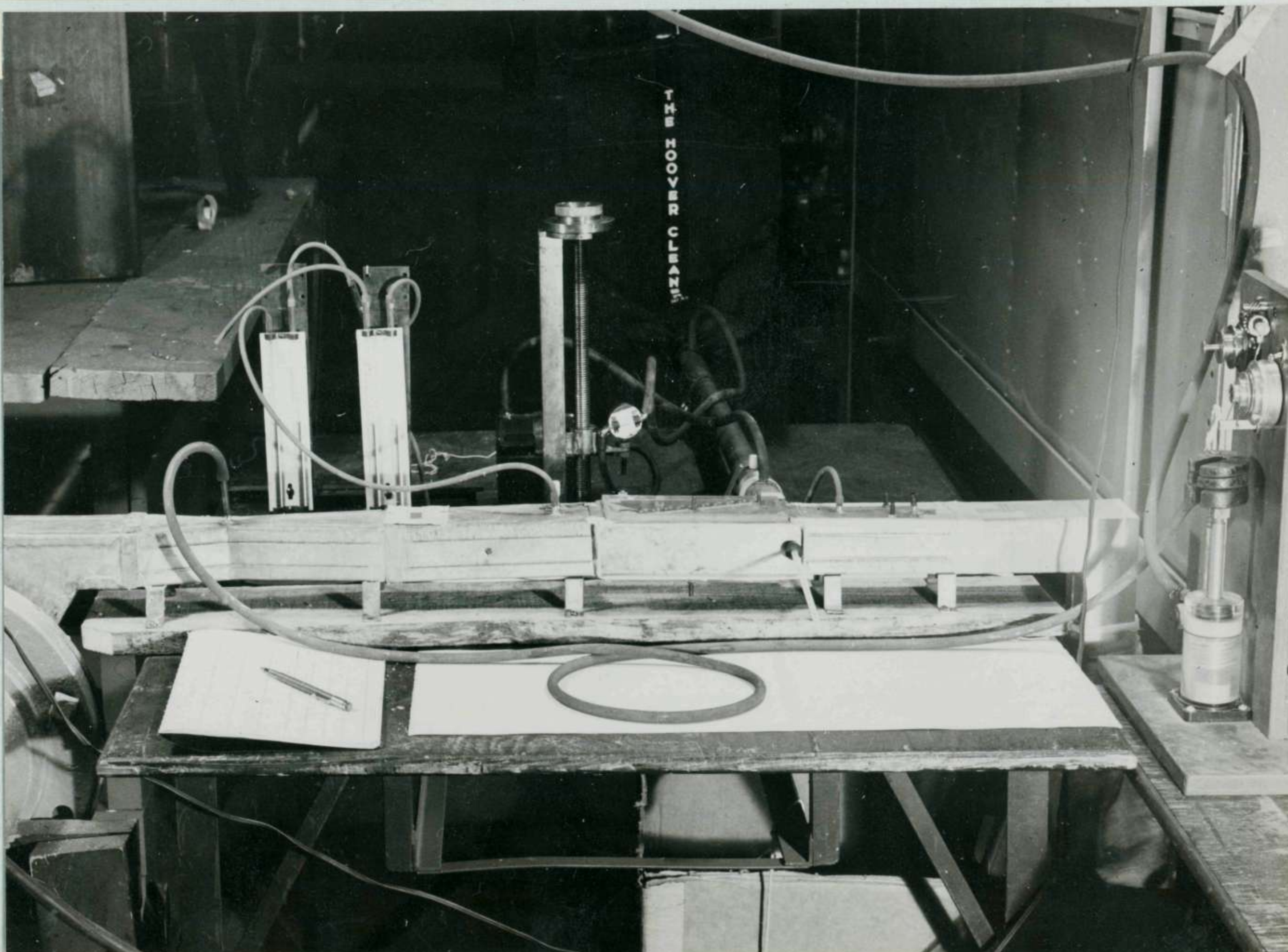


FIGURE 6

APPARATUS

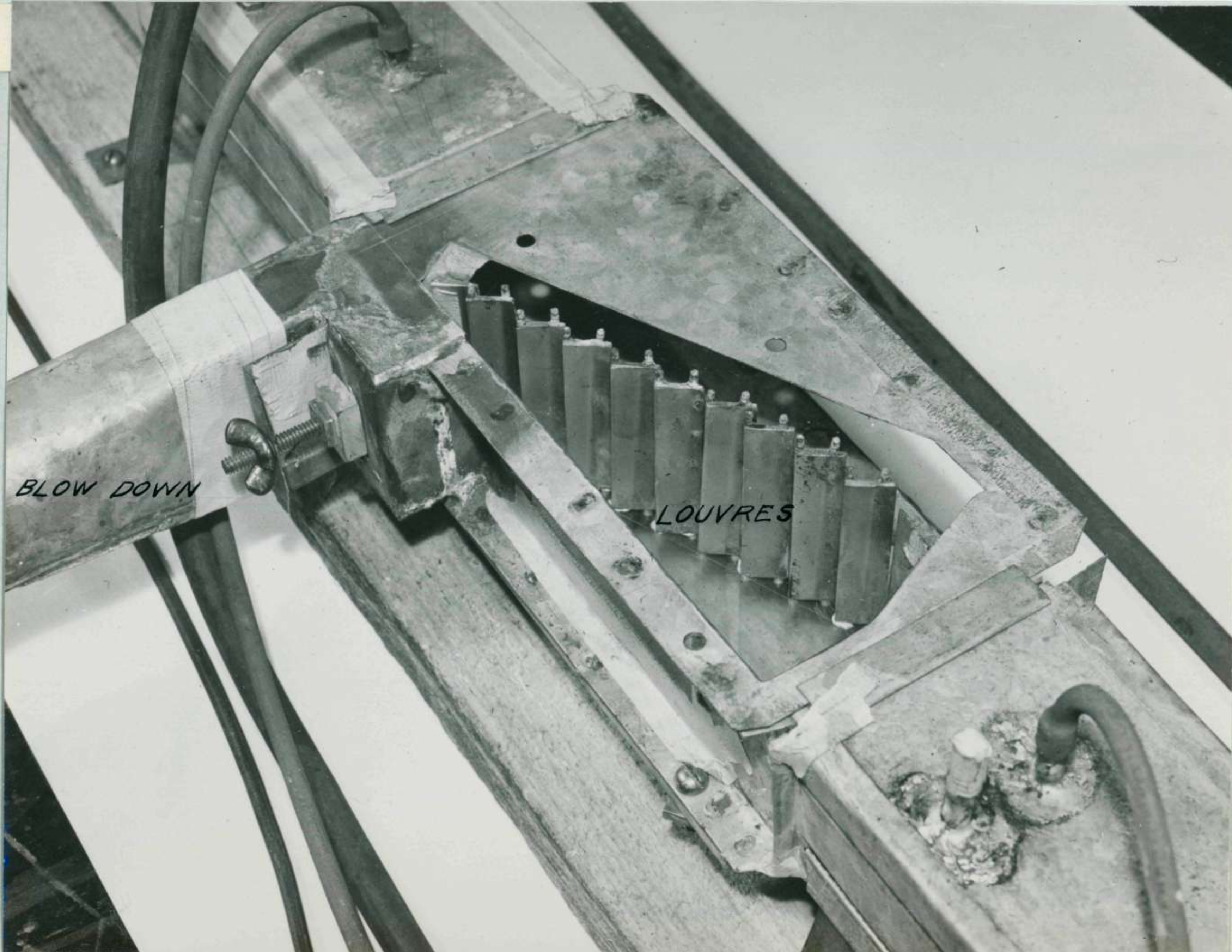


FIGURE 7

SEPARATOR

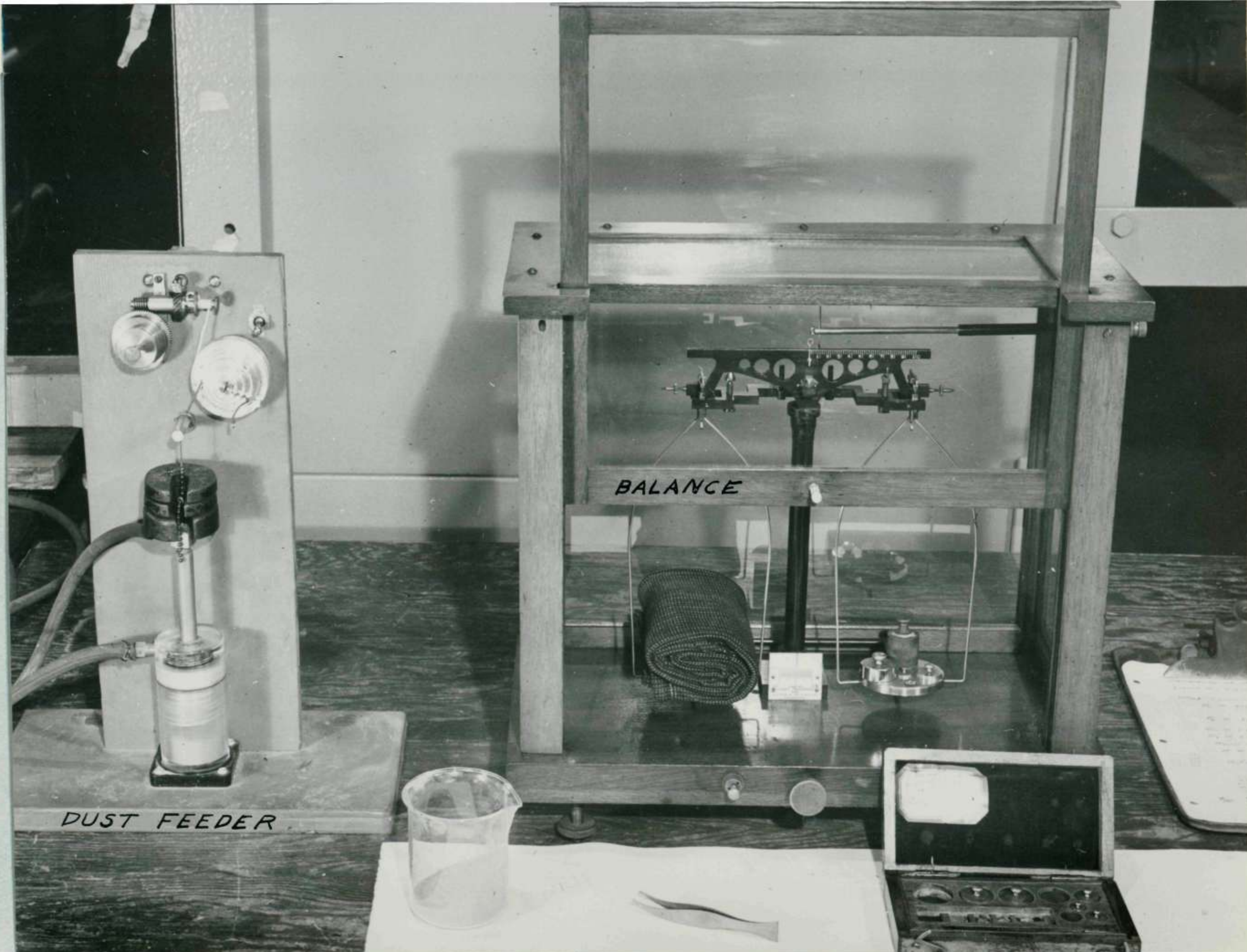
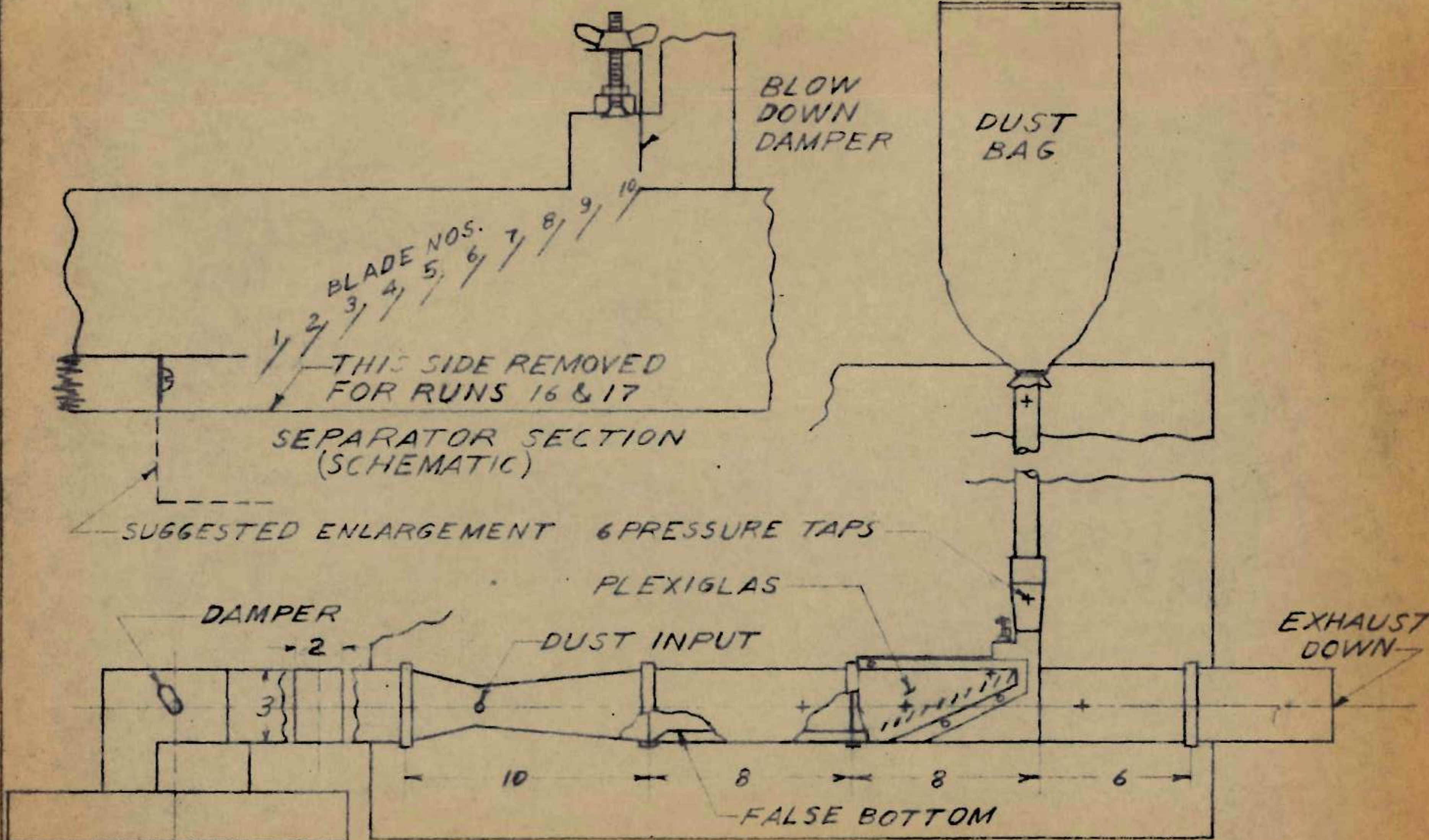


FIGURE 8

APPENDIX B

APPARATUS ILLUSTRATIONS



SCALE: 1 in = 0 ft — 6 in

FIGURE 9
PLAN VIEW OF APPARATUS

APPENDIX C

CALIBRATION OF AIR FLOW METERS

CALIBRATION OF AIR FLOW METERS

The total flow nozzle was calibrated against a Durley box which could be fitted with 5 orifices of from 1 to 3 inches in diameter. The coefficient of discharge of each orifice was known. The actual flow of air was calculated using

$$W = .01148\ c\ d^2\sqrt{\frac{Bh}{T}}$$

where W = flow lbs./sec
h = pressure in Durley box - inches of water
B = Barometric pressure - inches of mercury
T = Durley box temperature - °F abs.
c = coefficient of discharge
d = orifice diameter - inches

Then this flow was plotted against the nozzle pressure difference. See Figure 10, Curve 1. This curve can not be used unless the temperature of the air above the nozzle is up to its operating value of about 100° F.

The blow down pipe was calibrated against a discharge orifice for which the equation of flow was

$$W = 0.004\sqrt{h}$$

where W = flow lbs/sec
h = pressure difference - inches of water

Six runs were made and the actual flow was calculated using the above formula. This flow was then plotted against the pressure difference across the pipe in inches of alcohol. Since this curve had to be extrapolated beyond its upper end the formula

$$W = .015\sqrt{h}$$

where W = flow - lbs/sec
h = pipe drop - inches of alcohol

was used to calculate the blow down flow. This formula is plotted as Curve II, Figure 10. It is seen that it fits the data better at the upper end which is where most of the runs were taken.

TABLE VIII: Nozzle and Blow Down Pipe Calibration Data
Barometric Pressure 29.08 inches of Mercury
Room Wet Bulb Temperature 74° F
Room Dry Bulb Temperature 83.5° F

Durley Box			Nozzle		
Orifice Size Inches	P	T	DP	P	T
1.000	28.8	92	2.35	30.5	99
1.250	20.7	94	4.15	23.8	100
1.502	13.7	95	5.65	18.0	101
2.001	5.6	96	7.20	11.1	101
3.003	1.2	97	8.20	7.3	101

Discharge Orifice P	Blow Down Pipe DP[a]	Temperature °F
7.3	0.525	89
5.7	0.391	89
3.8	0.294	89
2.5	0.220	89
1.0	0.114	89
0.6	0.067	89

Durley Box Orifice
Coefficients

Orifice Size Inches	Coefficient
1.000	0.599
1.250	0.600
1.502	0.601
2.001	0.605
3.003	0.610

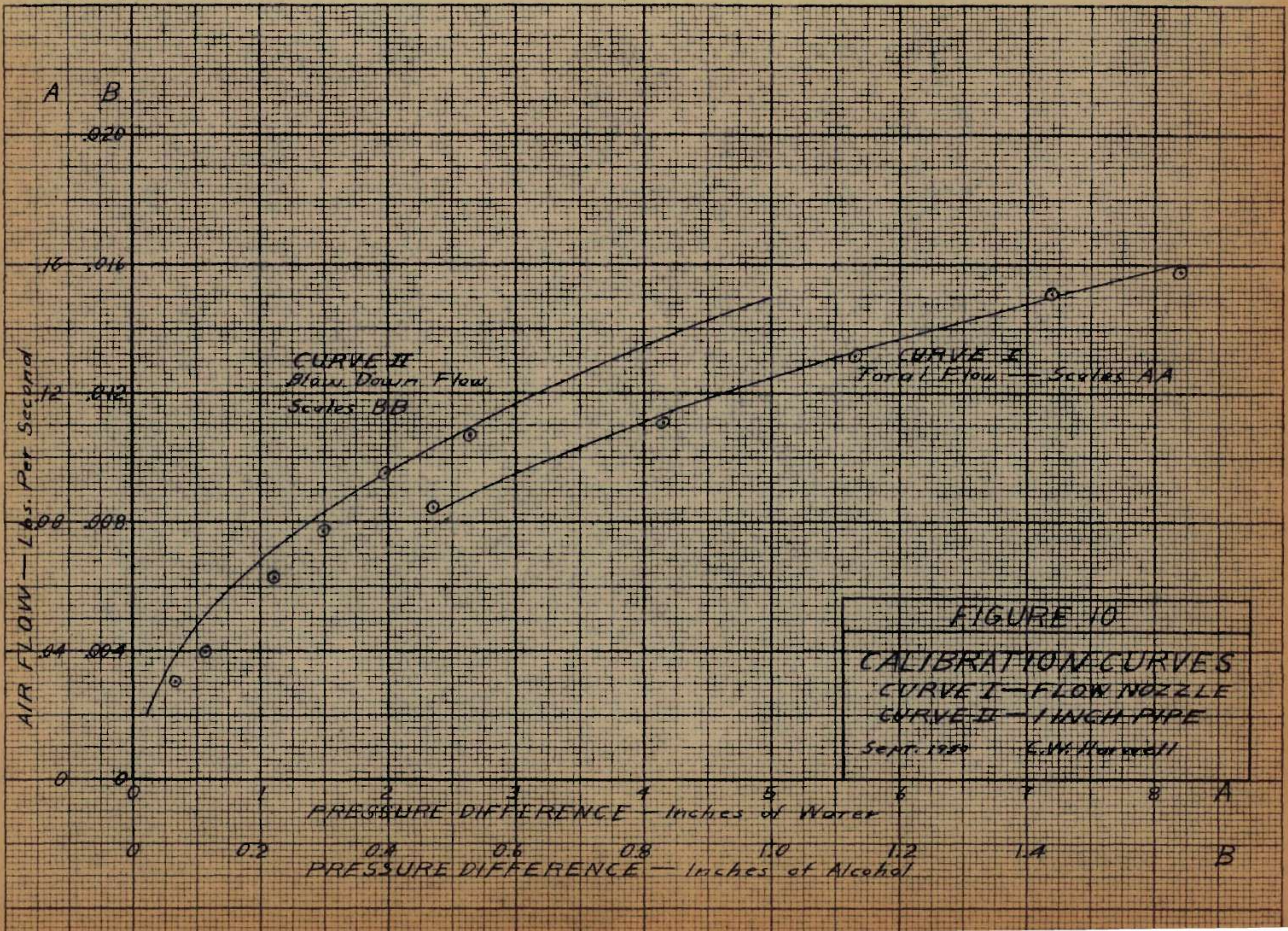


FIGURE 10
CALIBRATION CURVES
CURVE I — FLOW NOZZLE
CURVE II — 1 INCH PIPE
Sept.
CURVE I
Total Flow — Scales AA
CURVE II
Blow Down Flow
Scales BB
AIR FLOW — Lbs. Per Second
A B
.020
.16 .016
.12 .012
.08 .008
.04 .004
0 0
0 1 2 3 4 5 6 7 8 A
PRESSURE DIFFERENCE — Inches of Water
0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 B
PRESSURE DIFFERENCE — Inches of Alcohol